Lecture: September 29, 2010

- Next Observatory Wednesday October 6

4. A Universe of Matter and Energy

"The eternal mystery of the world is its comprehensibility. The fact that it is comprehensible is a miracle."

Albert Einstein (1879 – 1955)
Physicist

What are Matter and Energy?

matter – is material such as rocks, water, air.

energy – is what makes matter move!

Energy is measured in many different units.

The metric unit of energy used by scientists is:

Joule

4,184 joules = 1 calorie

Table 4.1 Energy Comparisons

Item	Energy (joules)
Average daytime solar energy striking Earth, per m^2 per second	1.3×10^3
Energy released by metabolism of one average candy bar	1×10^6
Energy needed for 1 hour of walking (adult)	1×10^6
Kinetic energy of average car traveling at 60 mi/hr	1×10^6
Daily energy needs of average adult	1×10^7
Energy released by burning 1 liter of oil	1.2×10^6
Energy released by fission of 1 kg of uranium-235	5.6×10^{13}
Energy released by fusion of hydrogen in 1 liter of water	7×10^{13}
Energy released by 1-megaton H-bomb	5×10^{15}
Energy released by major earthquake (magnitude 8.0)	2.5×10^{16}
U.S. annual energy consumption	10^{20}
Annual energy generation from the Sun	10^{34}
Energy released by supernova (explosion of a star)	10^{44}–10^{46}

Three Basic Types of Energy

- **kinetic**
  - energy of motion
- **potential**
  - stored energy
- **radiative**
  - energy transported by light

Energy can change from one form to another.

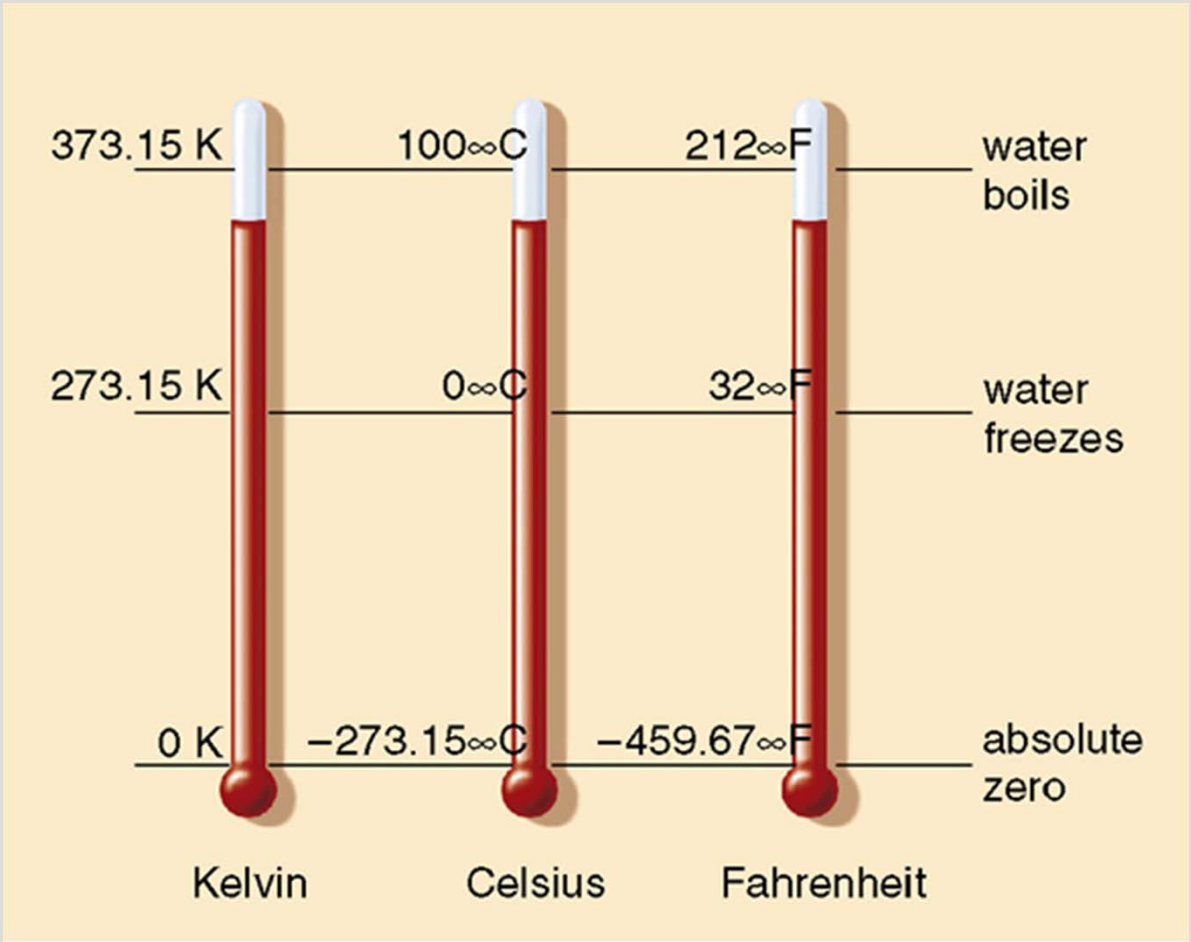
Kinetic Energy

- Amount of kinetic energy of a moving object
  = $1/2\ mv^2$

[if mass (m) is in kg & velocity (v) is in m/s, energy is in joules]

- On the microscopic level
  - the average kinetic energy of the particles within a substance is called the **temperature**.
  - it is dominated by the velocities of the particles.

Temperature Scales



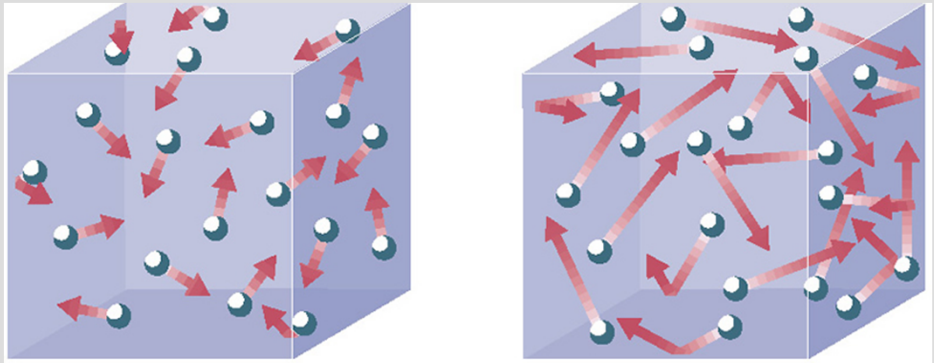
$$T_{Cel} = \frac{T_{Fah} - 32}{1.8}$$

$$T_{Fah} = 32 + (1.8 \times T_{Cel})$$

Temperature vs. Heat

lower T

higher T



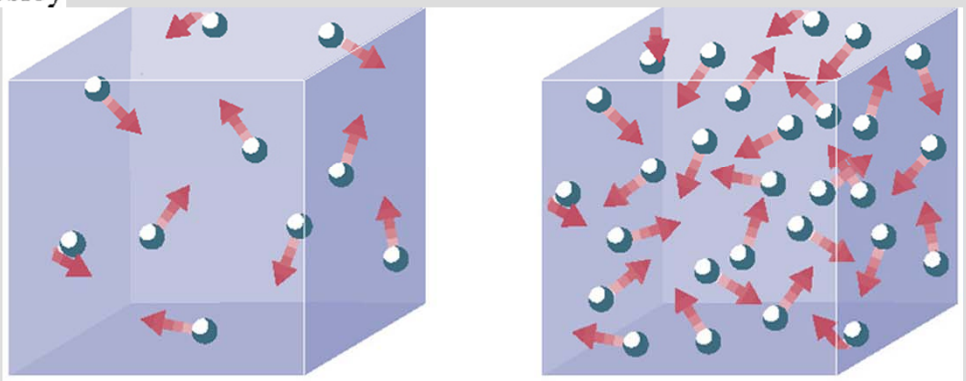
Longer arrows mean higher average speed.

- Temperature is the <u>average</u> kinetic energy.
- Heat (thermal energy) is the <u>total</u> kinetic energy.

less heat

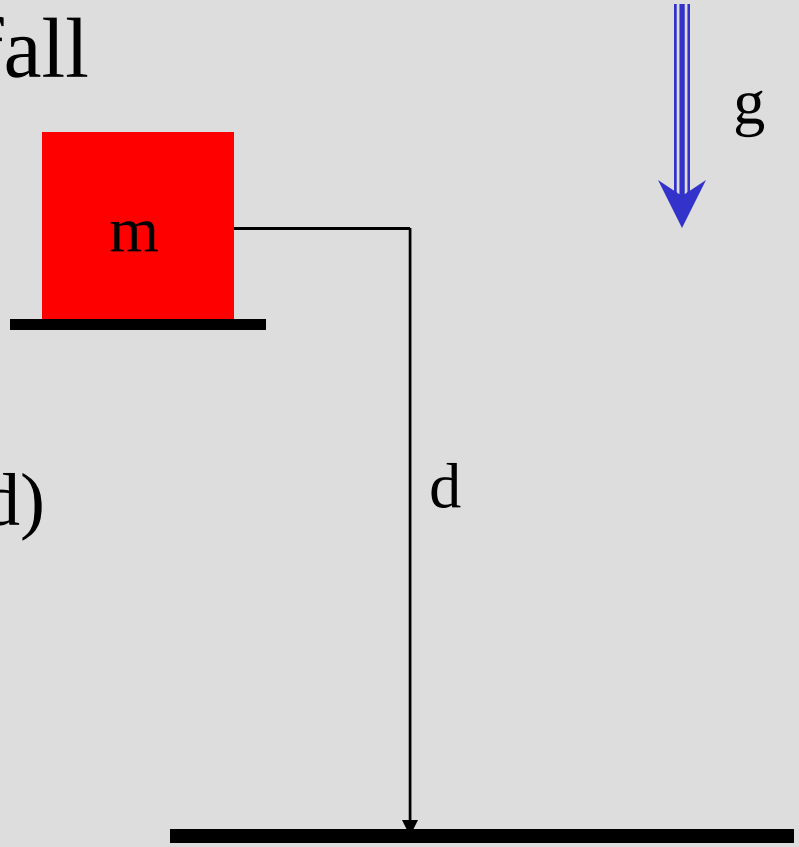
more heat

same T



Potential Energy

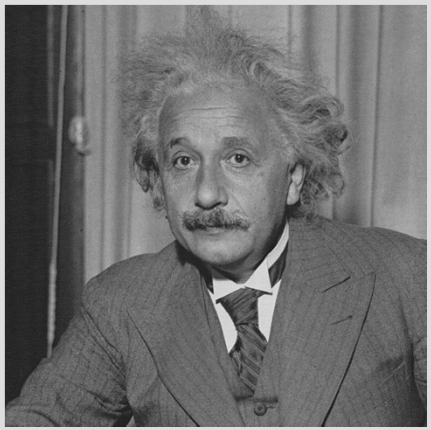
- *gravitational* potential energy is the energy which an object stores due to its ability to fall
- It depends on:
  - the object's mass (m)
  - the strength of gravity (g)
  - the distance which it falls (d)



Potential Energy

- energy is stored in matter itself
- this *mass-energy* is what would be released if an amount of mass, m, were converted into energy

$$E = mc^2$$

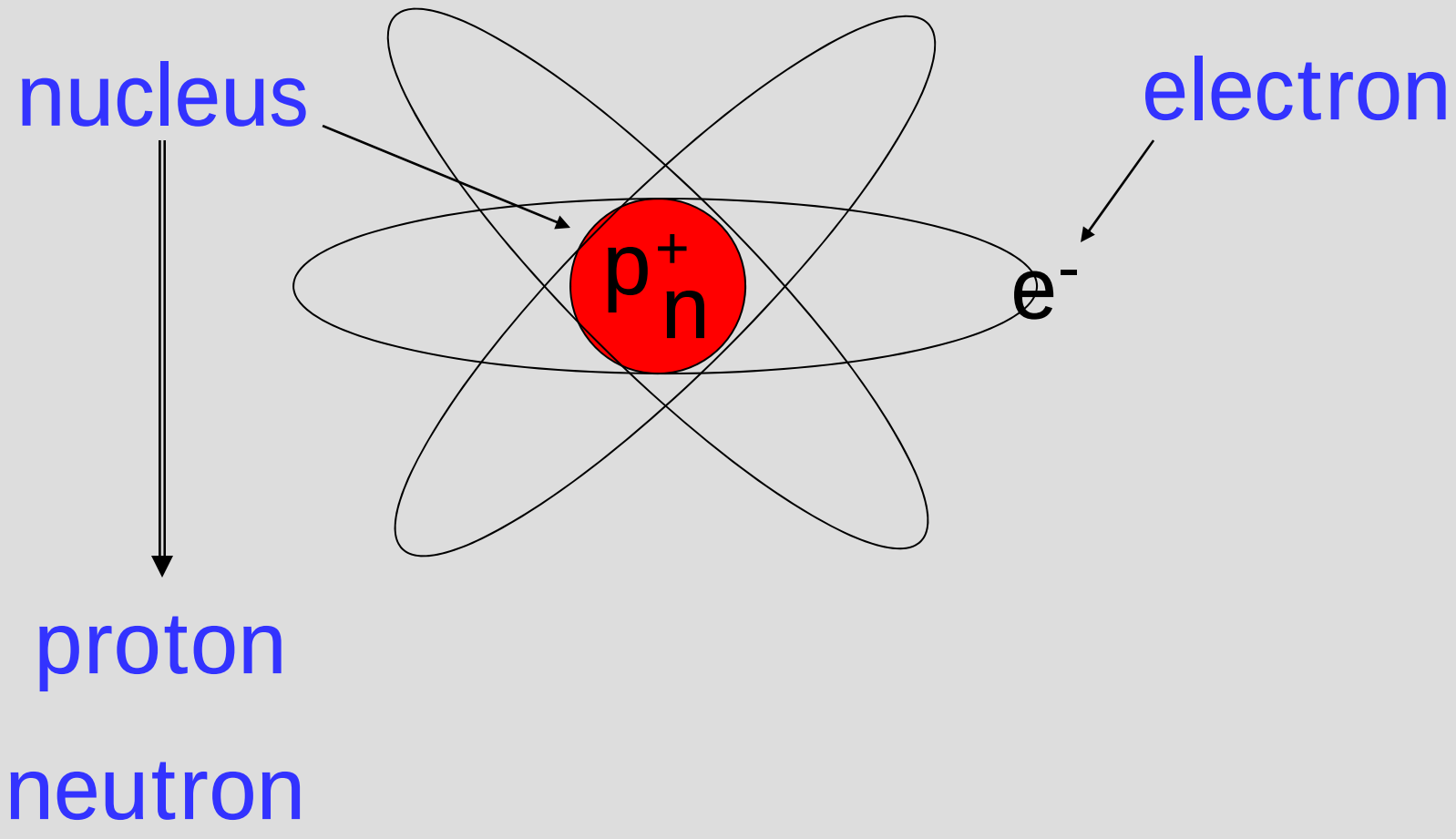


[c = 3 x 10^8 m/s is the speed of light; m is in kg, then E is in joules]

Conservation of Energy

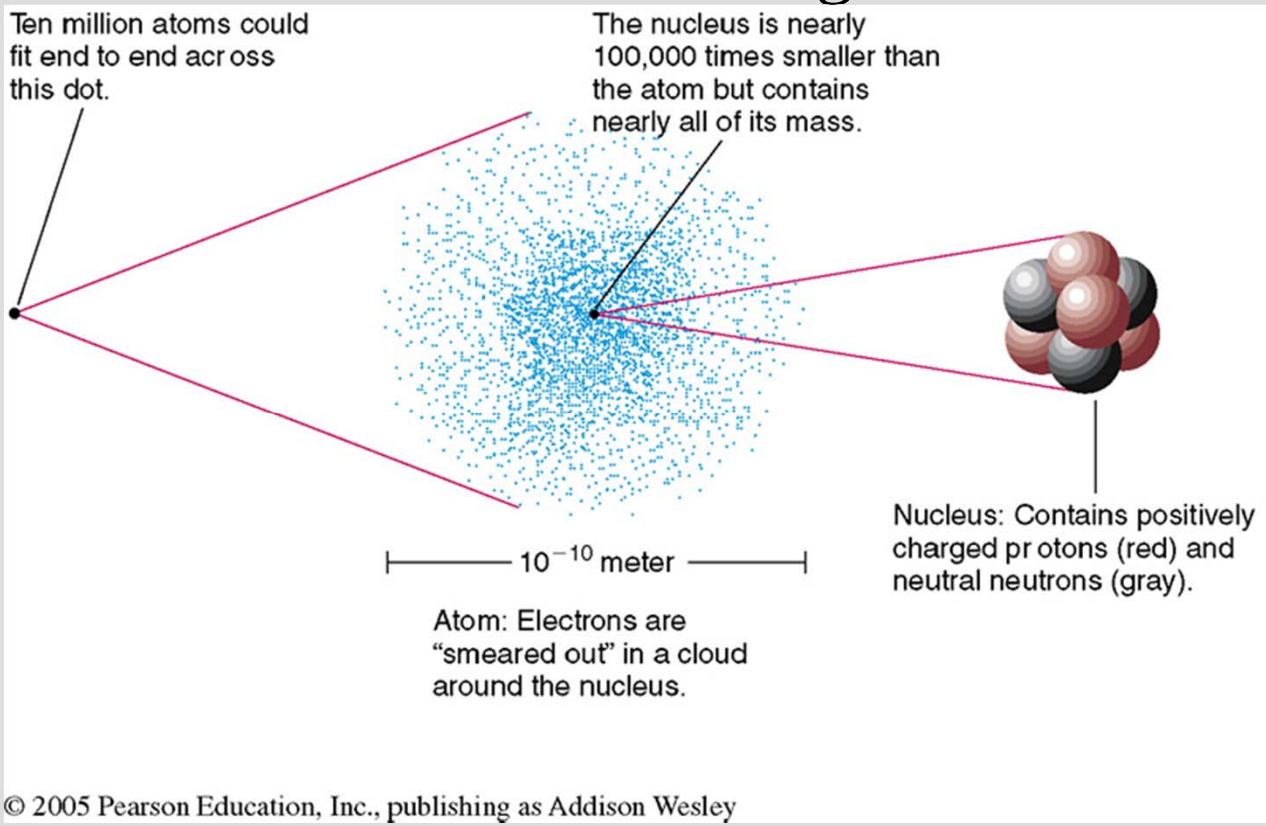
- Energy can be neither created nor destroyed.
- It merely changes it form or is exchanged between objects.
- This principle (or *law*) is fundamental to science.
- The total energy content of the Universe was determined in the Big Bang and remains the same today.

Atom

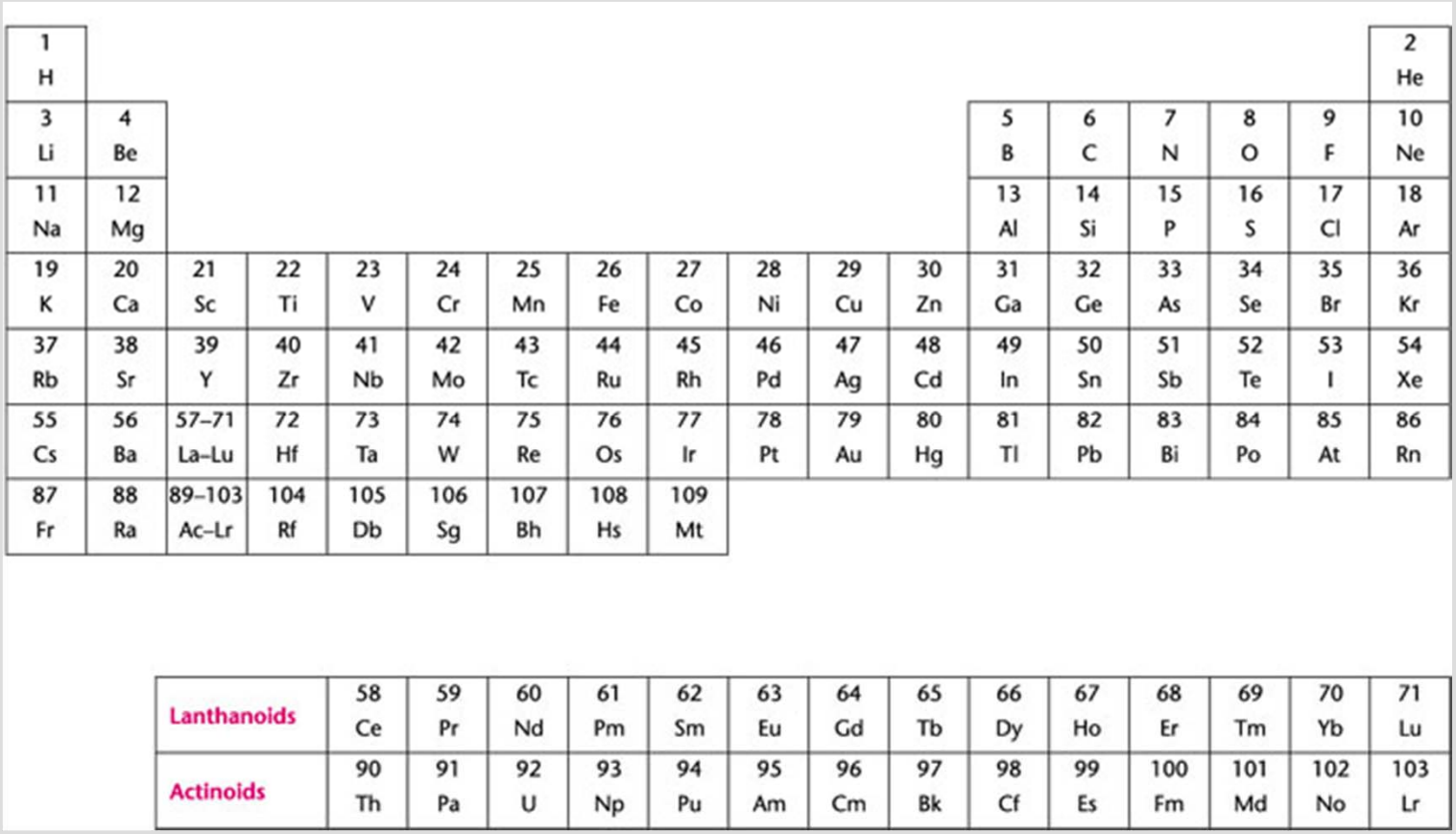


The “size” of an Atom

- Although it is the smallest part of the atom, most of the atom’s mass is contained in the nucleus.
- The electrons do not “orbit” the nucleus; they are “smeared out” in a cloud which give the atom its size.



Periodic Table of the Elements



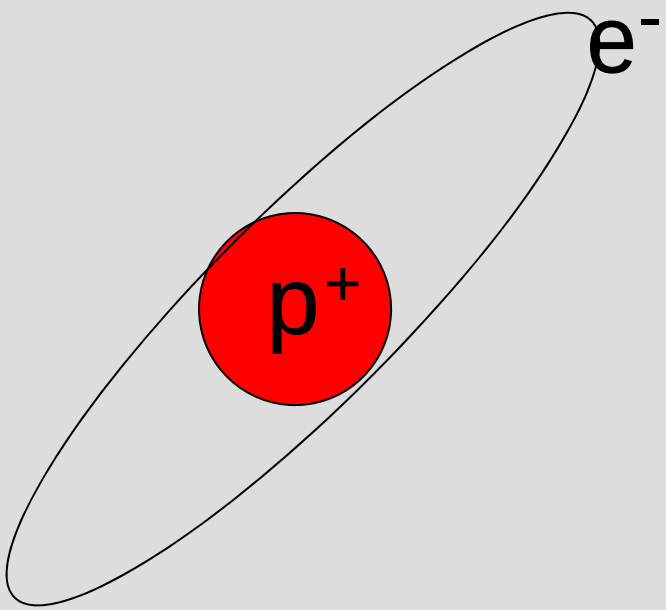
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57–71 La–Lu	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89–103 Ac–Lr	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt									

Lanthanoids	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
Actinoids	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr

atomic number = #protons

atomic mass no. = #protons + #neutrons

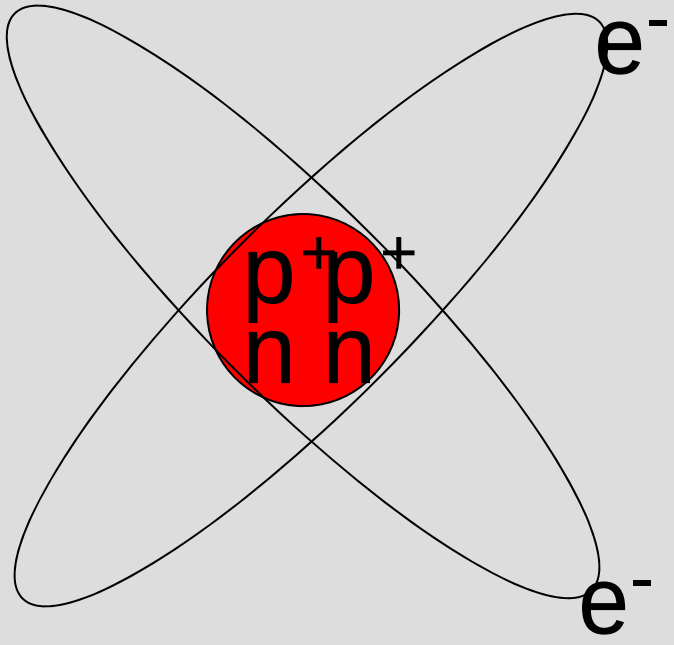
Hydrogen



atomic number = 1

atomic mass number = 1

Helium



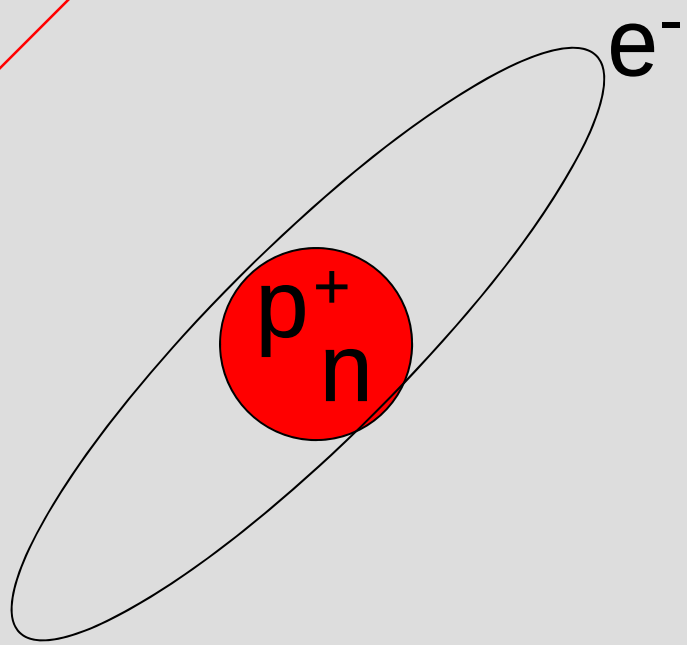
atomic number = 2

atomic mass number = 4

~~Hydrogen~~

Deuterium

isotope

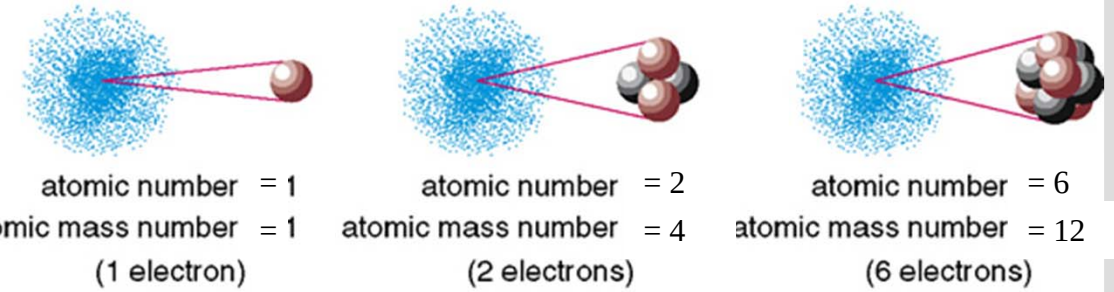


atomic number = 1

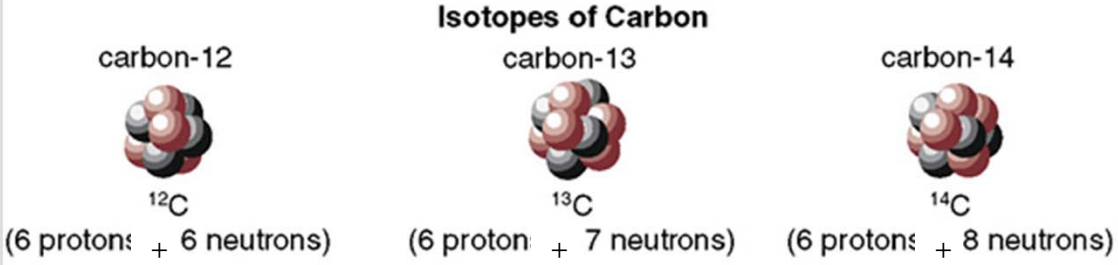
atomic mass number = 2

The particles in the nucleus determine the element & isotope.

atomic numbe = number of protons
atomic mass numbe = number of protons 1 neutrons



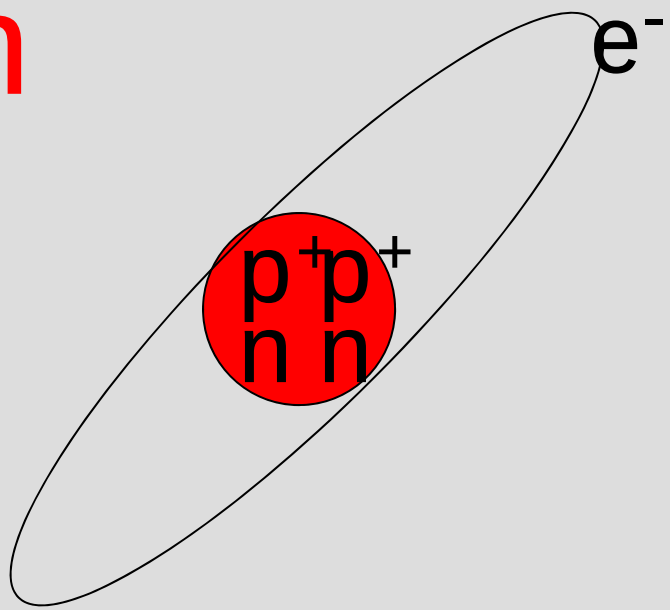
The number of electrons in a neutral atom equals its atomic number.



Different isotopes of a given element contain the same number of protons but different numbers of neutrons.

What if an electron is missing?

ion



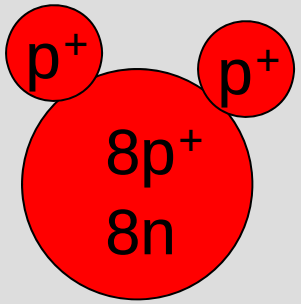
atomic number = 2

atomic mass number = 4

He^{+1}

What if two or more atoms combine to form a particle?

molecule

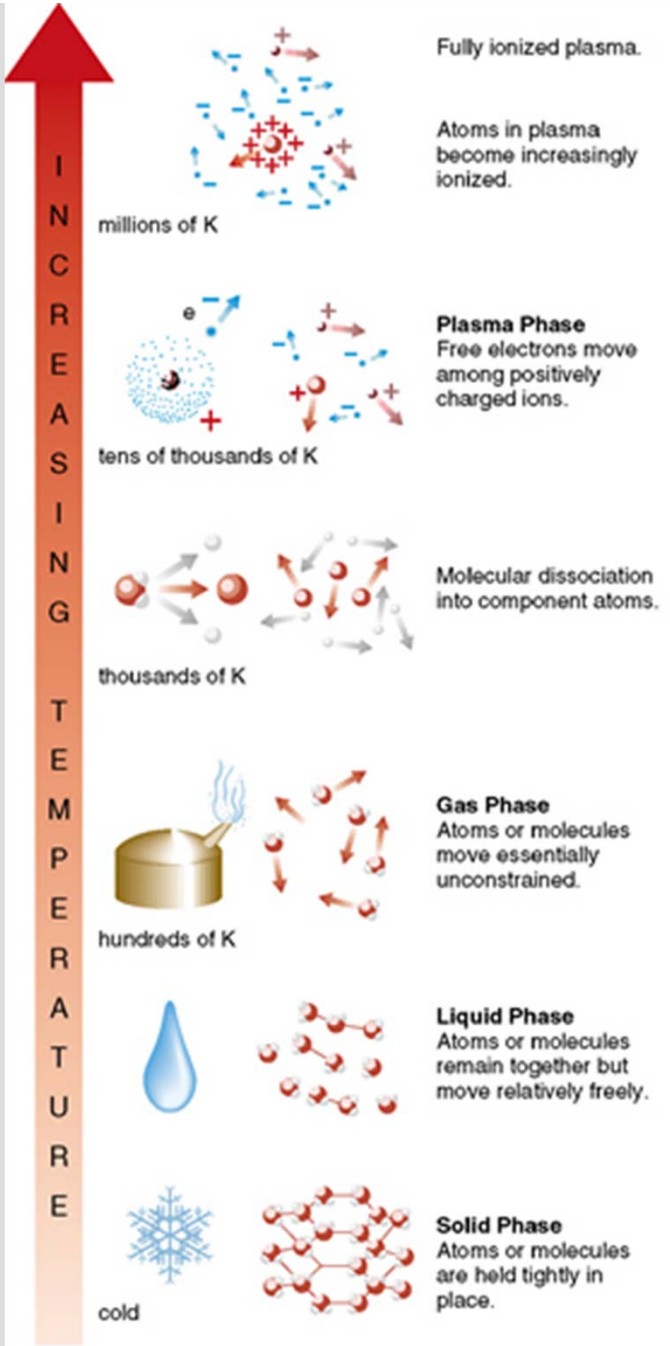


H_2O (water)

Phases of Matter

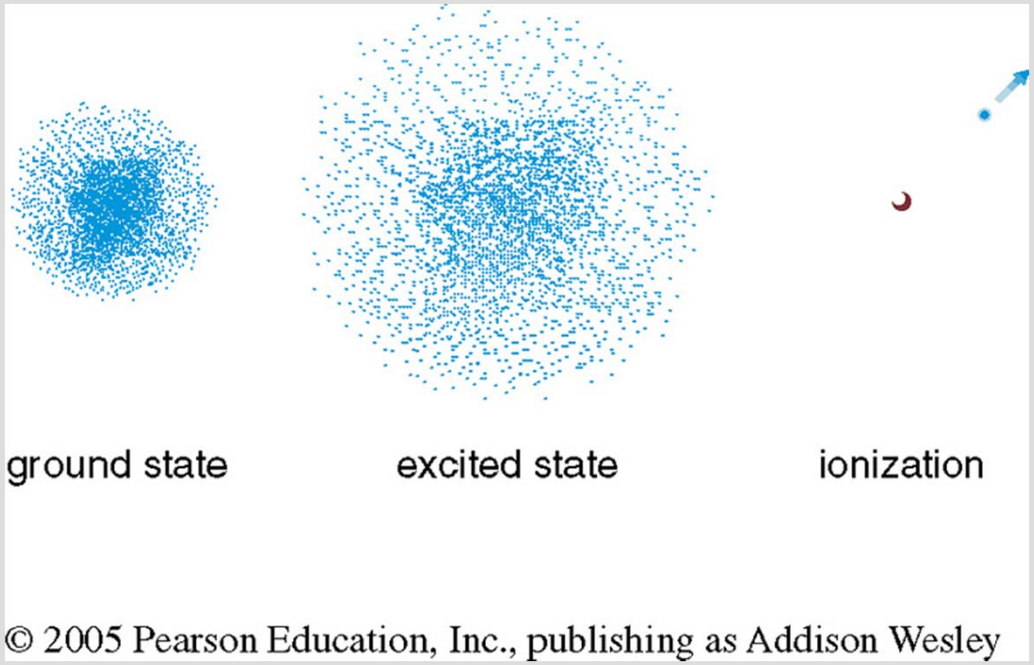
- the phases
  - solid
  - liquid
  - gas
  - plasma

  depend on how tightly bound the atoms and/or molecules are
- As temperature increases, these bonds are loosened:



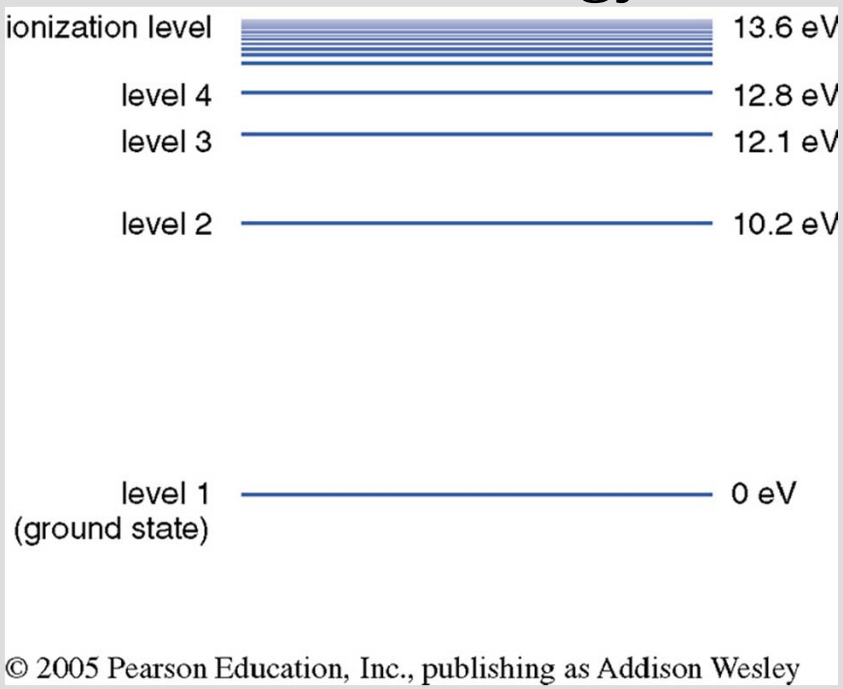
Electron Orbits

- Electrons can gain or lose energy while they orbit the nucleus.
- When electrons have the lowest energy possible, we say the atom is in the **ground state**.
- When electrons have more energy than this, we say the atom is in an **excited state**.
- When electrons gain enough energy to escape the nucleus, we say the atom is **ionized**.



Electron Energy Levels

- But, electrons can not have just any energy while orbiting the nucleus.
- Only certain energy values are allowed.
- Electrons may only gain or lose certain specific amounts of energy.



- Each element (atom and ion) has its own distinctive set or pattern of energy levels.
- This diagram depicts the energy levels of Hydrogen.

5. Universal Laws of Motion

"If I have seen farther than others, it is because I have stood on the shoulders of giants."

Sir Isaac Newton (1642 – 1727)
Physicist

Objects in Motion

- **speed –** rate at which an object moves, i.e. the distance traveled per unit time [m/s; mi/hr]
- **velocity –** an object's speed in a certain direction, e.g. "10 m/s moving east"
- **acceleration –** a change in an object's velocity, i.e. a change in either speed or direction is an acceleration [m/s^2]